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Vegetative and structural characteristics of agricultural drainages in the Mississippi Delta landscapes☆

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"Capsule": *Vegetated buffer areas provide effective mitigation for non-point source pollution from agriculture.*

Abstract

Agricultural drainage ditches in the Mississippi Alluvial Delta landscape vary from edge-of-field waterways to sizeable drainages. Ditch attributes vary with size, location and maintenance and may aid in mitigation of contaminants from agricultural fields. The goal of this study was to better understand how vegetative characteristics affect water quality in conveyance structures in the context of ditch class and surrounding land use. Characterization of 36 agricultural ditches included presence of riparian buffer strips, water depth, surrounding land use, vegetative cover, and associated aqueous physicochemical parameters. Vegetation was assessed quantitatively, obtaining stem counts in a sub-sample of ditch sites, using random quadrat method. Physical features varied with ditch size and vegetative diversity was higher in larger structures. *Polygonum* sp. was the dominant bed vegetation and was ubiquitous among site sizes. Macrophytes varied from aquatic to upland species, and included *Leersia* sp. and upland grasses (Poaceae family) in all drainage size classes. Percent cover of bed and bank varied from 0 to 100% and 70 to 100%, respectively, and highest nutrient values were measured in sites with no buffer strips. These conveyance structures and surrounding buffer zones are being ranked for their ability to reduce excess nutrients, suspended solids, and pesticides associated with runoff.

Keywords: Macrophytes; Conveyance structures; Vegetated buffer; Runoff; Mitigation

1. Introduction

Alluvial bottomlands formed in the lower Mississippi River Valley incorporate sections of northwestern Mississippi, northeastern Louisiana, eastern Arkansas and southeastern Missouri. Although this area contains the richest soils in the American South, it was sparsely settled as late as 1880, due largely to a harsh environment of swamplands, dense forests, physical isolation and endemic diseases (Otto, 1999). As early as 1891, an Indiana engineer introduced the idea of drainage systems in the Mississippi River Delta to gain access to more of the fertile alluvial soil. These ditch systems increased in popularity, as more land was needed for cotton production during World War I (Dougan, 1994). Agricultural drainage ditches in the Delta now include small edge-of-field conveyance structures which transit into large canals draining hundreds to thousands of hectares of farmland.

Awareness of possible agricultural contributions to non-point runoff necessitates that these drainage systems be considered for their mitigation of contaminants

☆ Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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from field runoff (Moore et al., 2000). The modification of runoff before reaching stream systems is often a function of the physical and biological attributes of ditches and their proximity and succession stage in relation to the drainage point of origin. Characteristics of these drainage systems (including riparian buffer strips, spoil size and surrounding land use), affect the quality and quantity of agricultural runoff entering the drainage system, while hydroperiod and water depth dictate vegetation types supported by these ecosystems. Single species assessments have been used to illustrate the value of plant and wetland characteristics affecting agricultural runoff (Karen et al., 1998), while less emphasis has been placed on macrophyte assemblages and their association with surrounding physical attributes of agricultural drainage systems.

Aquatic macrophytes have been shown to increase substrate, reduce velocity and accumulate suspended sediment from the water column (Gregg and Rose, 1982; Madsen and Warncke, 1983; Watson, 1987), increasing retention time and thus aiding in the remediation of aqueous and sediment-bound agricultural chemicals. In addition, aquatic macrophytes offer 20–50% removal efficiency of nitrogen and phosphorus (Brix and Schierup, 1989). Such reduction of nutrient transport has been shown by sediment retention within macrophyte beds (Sand-Jensen, 1998) and vegetated wetlands (Mitsch et al., 1995). Importance of retention time has also been noted for various pesticide uptake rates by macrophytes (Lytle and Lytle, 2002). The ability for mitigation of pesticides by aquatic vegetation continues to be investigated (Karen et al., 1998; Hand et al., 2001; Runes et al., 2001; Moore et al., 2002; Schulz et al., 2003).

Alternatively, nutrient loading leads to shifts in macrophyte communities from submerged to emergent vegetation (Phillips et al., 1978; Chambers, 1987; Hough et al., 1989; Janse, 1998) and these successions also follow sediment accretion (Bhowmik and Adams, 1989). Changes from submerged to emergent vegetation have been shown to decrease sediment resuspension and nutrients in the water column (Horppila and Nurminen, 2001; Madsen et al., 2001).

In developing a classification system for the different size ditches, structural conveyance capacity was utilized to organize observations into ditch classes. Characterization of these systems included macrophyte communities of bed and bank vegetation in primary contact with field runoff and therefore most likely to aid in mitigation of agricultural contaminants. These vegetative communities, along with physical characteristics, were assessed in agricultural drainage systems that ranged in size from primary, edge-of-field (<1 m wetted width), to larger ditches (8–10 m wetted width) that received combined drainage from smaller ditches. Physical characteristics, along with water regime and macrophyte density, were noted to determine the quality and quantity of runoff entering the systems and the system retention time at the time of sampling.

2. Methods and materials

2.1. Site location

Study sites were located in the Mississippi River Valley alluvial bottomlands, and assessed from May through August 2001. Twenty-four of 30 sites in Arkansas were located in the northeast Arkansas counties of Poinsett, Jackson, Craighead, Greene, Clay, Lawrence and Mississippi and six in the southeast Arkansas counties of Chicot and Desha (Fig. 1). Remaining study sites were located in Sunflower and Washington counties in west central Mississippi. Assessments were made on a 100 m upstream reach of each site's access point; exceptions were made when the upstream site was disturbed or inaccessible by wading.

2.2. Ditch size classification

After the establishment of ditch classifications, sites were categorized into size Classes 1–4 (Fig. 2). Hydraulic conveyance capacity determined the size classification, with structural depth and width defining this capacity. Edge-of-field systems draining a single agricultural field were generally classified as Class 1. Intermediate sizes included Class 2 sites, which usually received drainage from two to three fields or a confluence of Class 1 ditches, and Class 3 study sites, which were formed from the confluence of several edge-of-field ditches or Class 2 sites. Class 4 study sites were distinguished by near riverine capacities related to water retention, flow and minimum size. Ditches in larger classifications (3 and 4) not only received runoff water from smaller ditches in agricultural areas, but were also capable of receiving direct runoff from adjacent agricultural fields.

2.3. Vegetative and physical assessment

Quantification of vegetation covering at least 5% of the assessment area was made for each 10-m interval, resulting in 10 sub-samples from each site. Stem counts were performed on a random sub-sample of ditch sites using a 1 m^2 quadrat to obtain density for each species (stems/m^2). Assessment and subsequent correlation of stem count to percent cover were examined with simple linear regression. Submerged macrophytes were obtained with the use of a garden rake. On-site identification was performed whenever possible. If further identification was warranted, plants were returned to the laboratory on ice in sealed plastic bags containing wetted paper towels for moisture retention. Plants were identified according to Smith (1994), Borman et al. (1997), Whitley et al. (1999), Yatskievych (1999), and Crow and Hellquist

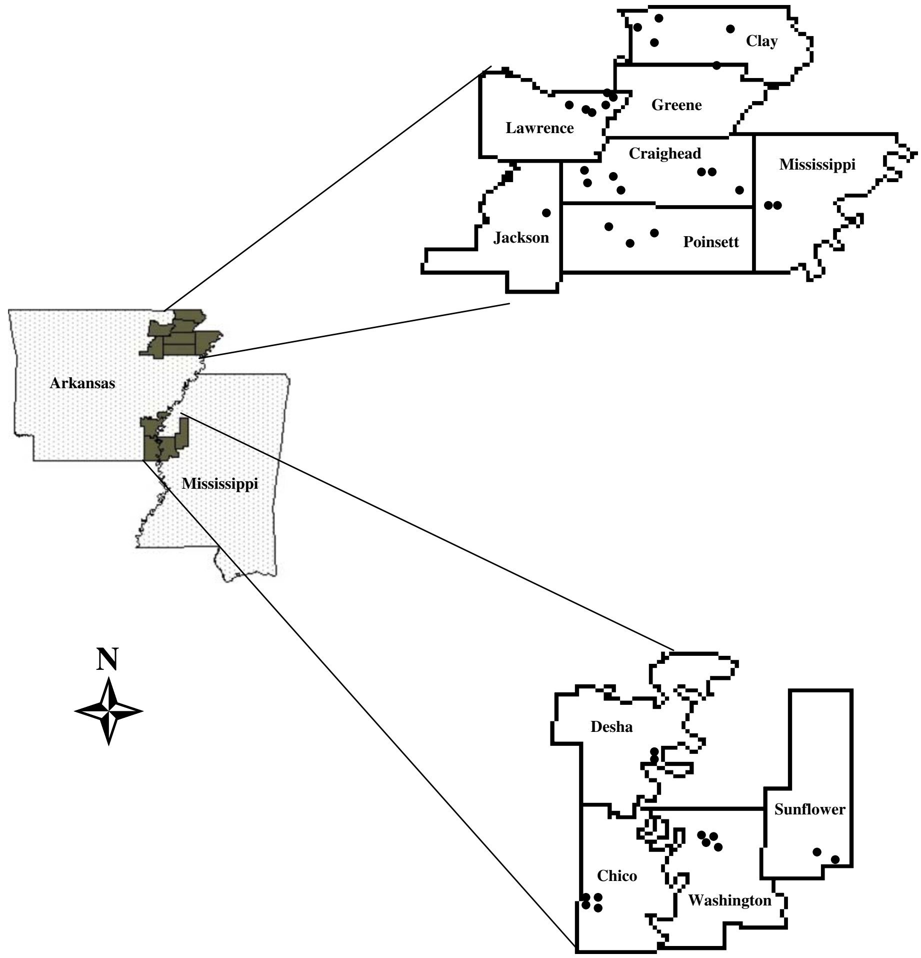

Fig. 1. Counties with study site locations in eastern Arkansas and western Mississippi, May–August 2001.

Fig. 2. (a) Representative vegetation in Class 1 ditch structure. (b) Absence of buffer strip in Class 2 ditch structure. (c) Class 3 ditch structure with diverse vegetation. (d) Deciduous forest and vegetated buffer strip aligning Class 4 ditch structure.

(2000). Classification to species was performed whenever possible, however, verification of Poaceae family was not achievable due to lack of inflorescences. Plant vouchers for each species are available in Arkansas State University's herbarium.

Each study site was evaluated for percent bed and bank cover within each 10-m interval prior to further vegetative assessment. Degree of water and vegetation contact during ditch hydroperiods was used in decisions of bed or bank assessment to include only bank vegetation exposed to water during flow events. Bed vegetation was assessed in study sites with $\geq$20% bed cover. In sites with sparse bed vegetation (<20%), bed and bank vegetation were assessed, with assessment area recorded for each site. Bank macrophytes were enumerated and identified in the absence of bed vegetation.

Surrounding land use was recorded, along with presence/absence of spoil and riparian zones. Surveying tapes were used to determine spoil width and height, top and bottom ditch width, buffer strip and riparian zone width, and recorded to the nearest 0.1 m. Ditch size, surrounding habitat, water regime and bank angle were also documented at the time of the assessment.

2.4. Additional parameter measurements

Concurrent with site assessment, various water quality parameters such as temperature, pH, dissolved oxygen and conductivity were measured at the study sites. Site waters were analyzed (after transport back to the laboratory) for alkalinity, hardness, nitrates, nitrites, phosphorus as orthophosphate, chlorophyll *a*, fecal coliforms and total, suspended, and dissolved solids. All water quality analyses followed American Public Health Association (APHA) (1998) guidelines utilizing a YSI Model 610 multi-meter, an Accumet AR 25 dual channel pH and ammonia meter, and a Hach DR 890 colorimeter. Nitrate (NO_3^-) determinations followed the cadmium reduction and diazotization method with a 0.01 mg/L detection limit. Nitrite (NO_2^-) determinations followed the diazotization method with a 0.005 mg/L detection limit. Soluble reactive phosphorus (PO_4^{3-}) determinations followed the ascorbic acid method with a 0.05 mg/L detection limit. Chlorophyll *a* concentrations were determined with a Beckman DU 640 spectrophotometer following APHA (1998) sample preparation methods. Microbial examination included enumeration of blue colonies for positive fecal coliform identification.

2.5. Statistical analysis

Results from the above observations were analyzed using simple regression and one-way analysis of variance (ANOVA) techniques. All tests for significance were conducted using $\alpha = 0.05$. For all analyses, data were tested for normality using Kolmogorov–Smirnov statistic and for homogeneity of variance using Bartlett's test (Minitab™, 2000).

3. Results

3.1. Vegetative assessment

Macrophyte assessments yielded 34 vegetative types ranging from obligate wetland to upland species for all classes ($n = 36$) (USDA, 2002). Three aquatic species and one upland family accounted for 90% coverage in Class 1 sites ($n = 7$) and were ubiquitous to all classes (Table 1). Macrophyte diversity was lowest in Class 1 sites with only nine vegetation types present. *Leersia* sp. accounted for 36% mean cover and occurred in 80% of Class 1 sites. *Polygonum* sp. and representatives from the grass family (Poaceae) were located in all of the Class 1 ditches, with a mean cover of 26.6% and 20.4%, respectively. Representatives from the Poaceae family included common Bermuda grass (*Cynodon dactylon*) and Johnson grass (*Sorghum halepense*). *Potamogeton* sp. accounted for 7% vegetative cover and was present in 20% of Class 1 sites.

Species richness increased from nine in Class 1 sites to 20 in Class 2 ($n = 8$) and 22 in Class 3 sites ($n = 13$). An increased abundance of Poaceae (21% mean cover) was noted in 62.5% of Class 2 sites. *Polygonum* sp. covered 12.9% and occurred in 75% of sites. Of the 22 species noted in the Class 3 sites, Poaceae represented 28.9% cover and appeared in 79% of sites. *Leersia* sp. was present in 36% of sites with 11.1% cover, while *Polygonum* sp. was present in 43% of Class 3 ditches and decreased in abundance to 4.8%.

Obligate wetland plants comprised 97% of the 18 species noted in Class 4 sites ($n = 8$). *Polygonum* sp. increased in abundance to 43.7% cover, occurring in 87.5% of sites. *Ludwigia peploides* occurred in 25% of surveyed sites, and formed 13.8% of the mean cover; while *Potamogeton* sp. was present in only 12.5% of sites, and accounted for 11.3% cover. Occurring with less frequency than in smaller sites was *Leersia* sp. and Poaceae (6.3% and 0.9% cover, respectively).

The presence of *L. peploides* and *Lemna minor* was apparent in all size classes larger than size one. *L. minor* was never a dominant species, however *L. peploides* constituted 13.8% mean cover and was dominated only by *Polygonum* sp. in Class 4 sites.

Vegetative bed cover decreased with increasing size of drainage system. Class 1 sites averaged 60% cover, while intermediate size ditches (Classes 2 and 3) varied the most (0–100%) but averaged 36 and 47%, respectively. Class 4 ditches ranged in bed cover from 0 to 90% with mean bed cover of 34%. Bank vegetation was less variable with size, and ranged from 86% for Class 3 to 93% for Classes 2 and 4.

Table 1
Vegetative mean percent cover and percent occurrence per ditch size, May through August 2001

Wetland classification[a]	Species	Ditch Class 1 Mean % cover	1 % Occurrence	2 Mean % cover	2 % Occurrence	3 Mean % cover	3 % Occurrence	4 Mean % cover	4 % Occurrence
OBL	*Alisma* sp. (water plantain)							1.3	25
OBL	*Cephalanthus occidentalis* (buttonbush)			1.3	25	2.1	7	1.9	25
OBL	*Eleocharis* sp. (spikerush)			1.3	12.5	2.1	7		
OBL	*Heterantehera reniformis* (mud plantain)	4.0	20	0.6	12.5				
OBL	*Hibiscus* sp. (rose-mallow)			0.6	12.5	0.4	7		
OBL	*Leerisa* sp. (cutgrass)	36.0	80	5.0	25	11.1	36	6.3	25
OBL	*Lemna minor* (duckweed)			3.8	25	1.4	21	4.4	25
OBL	*Lindernia dubia* (false pimpernel)	1.8	20						
OBL	*Ludwigia peploides* (water primrose)			5.0	37.5	13.1	29	13.8	25
OBL	*Myriophyllum* sp. (coontail)					1.4	7	1.3	12.5
OBL	*Nymphaea* sp. (water lily)					0.4	7		
OBL	*Polygonum* sp. (smartweed/knotweed)	26.6	100	12.9	75	4.8	43	43.7	87.5
OBL	*Potamogeton* sp. (pond weed)	7.0	20	4.4	25	2.1	21	11.3	12.5
OBL	*Ranuculus* sp. (crowfoot)			1.3	12.5				
OBL	*Sagittaria* sp. (arrowhead)			1.3	12.5			1.3	12.5
OBL	*Salix nigra* (black willow)			0.6	12.5	0.4	7	0.6	12.5
OBL	*Scirpus* sp. (bullrush)	0.4	20	2.5	12.5			0.6	12.5
OBL	*Spirodela polyrhiza* (great duckweed)					0.4	7		
OBL	*Typha latifolila* (cat-tail)	1.2	40			1.4	21	0.6	12.5
FACW+	*Juncus* sp. (soft rush)			1.9	25	0.7	14		
FACW+	*Phyla lanceolata* (northern frog-fruit)			6.7	12.5			0.8	12.5
FACW	*Brunichia cirrhosa* (eardrop vine)			9.5	25				
FACW	*Cyperus odoratus* (flat sedge)	0.6	20						
FACW–	*Stachys tenuifolia* (hedge-nettle)					1.9	7	4.0	12.5
FAC+	*Eupatorium* sp. (boneset/thoroughwort)					5.7	14		
FAC	*Campsis radicans* (trumpet vine)			2.7	12.5	2.3	7	2.0	12.5
FAC	*Cyperus esculentus* (yellow nut-grass)							0.6	12.5
FAC–	*Chenopodium album* (pigweed)					2.9	14		
FAC–	*Lonicera japonica* (honeysuckle)			7.3	25				
FACU+	*Phytolacca americana* (pokeweed)					1.4	21	2.5	12.5
FACU	Poaceae (grass family)	20.4	100	21.0	62.5	28.9	79	0.9	12.5
FACU	Rosaceae (rose family)			2.5	25				
UPL	*Rubus allegheniensis* (blackberry)					3.6	7		
NI	*Lespedeza* sp. (bush clover)					7.4	43		
	Miscellaneous species[b]	2.0		8.1		4.0		2.2	

OBL = obligate wetland species, FACW = facultative wetland species, FAC = facultative species, FACU = facultative upland species, UPL = upland species, NI = not indicated.

[a] Wetland classification according to USDA, NRCS (2002).

[b] Miscellaneous species = species with <5% cover at any site.

Correlation of stem count to percent cover with simple linear regression was not possible for members of the Poaceae family due to size variability. After excluding two unusual observations, there was a strong linear correlation of *Polygonum* sp. stem count with percent cover ($r^2 = 97.7\%$). The following regression equation ($n = 18$, P value < 0.05) was applied to the data:

$$Polygonum\ \text{sp. stem count/m}^2 = -19.0 + 5.88 \times \%\ \text{cover}$$

L. peploides stem count to percent cover regression equation ($r^2 = 84.6\%$, $n = 13$) resulted in a P value < 0.05:

$$L.\ peploides\ \text{stem count/m}^2 = -1.91 + 1.32 \times \%\ \text{cover}$$

3.2. Surrounding land use

Surrounding land use for sites was primarily row-crop agriculture of cotton (*Gossypium herbaceum*), soybeans (*Glycine max*), rice (*Oryza sativa*) and corn (*Zea mays*). In addition, seven sites were adjacent to agricultural access roads. Aquaculture ponds adjoined two sites in Class 3 category, buffered by vegetated strips measuring 3–4 m at one site and 1-m buffer strips at the other. A 2-m deciduous buffer strip divided a sewage pond and a Class 4 site with a deciduous forest on the opposing bank. A golf course was located adjacent to a Class 2 site in Mississippi buffered by a 3-m vegetated strip; a 1-m grass buffer strip separated emergent beans on the opposing side.

3.3. Physical characteristics

Bottom and top ditch width were used as criteria for developing the size classes. Class 1 sites had bottom widths (wetted zone) from 0.5 to 2.0 m and top widths from 0.5 to 5.0 m (mean = 2.8 m). Class 2 sites had bottom widths from 1.5 to 3.0 m and top widths from 2.0 to 5.0 m, while mean bottom and top widths of 5.3 and 9.6 m, respectively, classified the Class 3 sites. The largest study sites (Class 4) had mean bottom and top widths of 8.3 and 19.5 m, respectively. Hydroperiod was Class dependent, and Class 1 sites were characterized by standing water or dry conditions. Standing water with and without flow was recorded for all intermediate class sites and Class 4 sites presented either standing water with flow or riverine (moderate to fast flow) conditions. Bank angles were the smallest in Class 1 sites with a mean = 45°, the two intermediate ditch classes had the largest bank angles (mean = 67° and 69°, respectively), while the bank slopes for Class 4 sites averaged 51°. Spoil size was absent or notably small in all classes except Class 4 where heights up to 4.5 m were measured.

3.4. Physicochemical parameters

Physicochemical parameters were summarized according to size classification of each study site (Table 2). Highest mean nitrate (2.44 mg/L) and nitrite (0.591 mg/L) and the highest overall nitrate (7.80 mg/L) levels were measured from Class 1 sites. Although highest nitrate and nitrite values were recorded for a Class 2 site of 2.43 and 1.23 mg/L, respectively, mean nitrate values were lowest for Class 2 and 3 sites (0.43 mg/L and 0.22 mg/L, respectively). Maximum values for Class 3 sites were 1.53 mg/L (nitrates) and 0.21 mg/L (nitrites). Mean orthophosphate values were highest in Classes 1 and 4 (1.10 mg/L and 1.16 mg/L, respectively) with maximum values as high as 2.56 mg/L for a Class 1 site and 2.28 mg/L for a Class 4 site. The highest chlorophyll *a* values of 703.94 mg/L and 313.81 mg/L were measured in Class 1 and 3 ditches, respectively, while the lowest was in a Class 4 site (3.75 mg/L).

Table 2
Measured physicochemical parameters for ditch sites by size classification, May–August 2001

Class size	1 (n = 7)	2 (n = 8)	3 (n = 13)	4 (n = 8)
TSS (mg/L)	64 ± 78	71 ± 111	59 ± 79	53 ± 37
Turbidity (NTU)	43 ± 43	111 ± 190	48 ± 61	66 ± 62
pH	8.16 ± 0.65	7.62 ± 0.22	8.13 ± 0.73	7.88 ± 0.78
Dissolved oxygen (mg/L)	11.3 ± 6.2	6.7 ± 1.4	7.0 ± 2.8	8.2 ± 4.6
Conductivity (μS/cm)	405 ± 159	354 ± 143	369 ± 103	395 ± 251
Temperature (°C)	25.3 ± 5.4	27.5 ± 3.4	27.3 ± 4.1	27.1 ± 4.6
Alkalinity (mg/L)	105 ± 12	120 ± 76	136 ± 48	127 ± 55
Hardness (mg/L)	144 ± 54	140 ± 87	130 ± 44	156 ± 85
Nitrates (mg/L)	2.44 ± 3.52	0.43 ± 0.98	0.22 ± 0.49	0.81 ± 1.40
Nitrites (mg/L)	0.591 ± 0.815	0.387 ± 0.584	0.042 ± 0.067	0.141 ± 0.191
Ortho phosphorous (mg/L)	1.10 ± 1.07	0.75 ± 0.38	0.70 ± 0.61	1.16 ± 0.53
Chlorophyll *a* (mg/L)	201.19 ± 284.04	30.54 ± 14.11	68.57 ± 77.94	30.15 ± 31.88
Fecal coliforms (cfu/100 ml)	1905 ± 2578	4239 ± 6846	624 ± 1371	2443 ± 5025

Means ± 1 SD provided.

High variability in total suspended solids (TSS) and turbidity values were measured in ditches from each size class, with a Class 2 site measuring 290 mg/L and 496 NTU, respectively. High values included 197 and 222 NTU turbidity in Class 3 and 4 sites, respectively, and 153 and 180 mg/L TSS in Class 3 and 1 sites, respectively. Conversely, low TSS and turbidity of ≤ 5 mg/L and ≤ 10 NTU were measured from each class. After excluding two unusual observations, turbidity values in conveyance structures with $\geq 20\%$ vegetative bed cover were found to be significantly different from values in structures with $< 20\%$ bed cover ($P < 0.05$) (mean values 36.7 and 94.8 NTU, respectively). Fecal coliform values also exhibited variability in all size class sites, ranging from 0 to $> 20\,000$ cfu/100 ml.

4. Discussion

In this study, macrophyte communities in conjunction with agricultural ditch characteristics were assessed to rank the importance of site characteristics and in-place communities that determine the efficiency of agricultural runoff mitigation. Attributes can be ranked through benefits obtained according to class size of conveyance structures. While conventional best management practices (BMPs) include buffer strips proximal to receiving streams, consideration should be given to existing macrophyte assemblages in receiving ditches that provide contact with runoff during transfer to these streams. In smaller class ditches vegetative communities could provide mitigation similar to riparian corridors by offering a spatial buffer for non-point agricultural runoff (Moore et al., 2000). Since persistent inundation in larger class ditches rarely offers the opportunity for bed vegetation, grassed or forested buffer strips are critical to the reduction of runoff related contaminants from adjacent fields. When runoff delivery is considered for retention time and water/macrophyte contact, sheet flow through vegetated buffer strips may provide the only mitigation prior to entry into agricultural conveyance structures.

Spatial and temporal aspects of the conveyance structures should be considered when ranking attributes by class size. Smaller ditch sizes have higher water retention time, more bed vegetation and are usually located further from receiving streams. Direct runoff entering these ditches may have sufficient macrophyte/water contact to mitigate agricultural associated contaminants prior to entrance into receiving streams. Larger conveyance structures frequently have a shorter water retention time, less bed vegetation and are often in closer proximity to receiving streams. To realize BMPs, direct runoff entering these systems must have mitigation through macrophyte/water contact such as vegetated buffer strips prior to entry into larger systems.

Agricultural conveyance structures in the Mississippi Alluvial Delta have been recognized as comparable substitutes for edge-of-field wetlands (Moore et al., 2000) and can provide areas of mitigation of non-point source contamination. De Laney (1995) found that constructed wetlands surrounded by grassed buffer strips could effectively reduce as much as 80% of sediment in the water column and at least 90% of transported nutrients provided sheet flow is maintained. Grassed buffer strips edging agricultural conveyance structures can enhance mitigation of non-point contamination prior to water leaving conveyance systems, thereby increasing effectiveness of combined mitigation of buffer strips and vegetated ditches.

In the current study, nutrients were highest for all class sizes at sites with limited or no buffer strips separating emergent crops from runoff. These included sites with the highest nitrate (7.80 mg/L) and orthophosphate (2.56 mg/L) values. Conversely, despite size of conveyance structure, sites with associated buffer strips ranging from 5 m grassed strips to forested buffers had no measurable nitrate values. Orthophosphate removal was less predictable. Runoff loss of phosphorus has been shown to be affected by site variability in erosion processes, soil management and topography (Sharpley et al., 1994).

Macrophyte removal of suspended solids from the water column was demonstrated by the presence of bed vegetation. Sites with low percent cover of bed vegetation ($< 20\%$) showed significantly higher turbidity values than sites with $\geq 20\%$ vegetative cover, with the exception of two sites with 50% and 70% cover. These exceptions may have been due in part to effects from eutrophication at the site with 70% bed vegetation (chlorophyll $a = 703.94$ mg/L) and a storm event for the sample from the site with 50% cover. Hydraulic roughness due to vegetation was calculated using the Manning equation and had an inverse relationship with discharge and the Manning coefficient, n, (Mitsch and Gosselink, 2000) except during major discharge events (Madsen et al., 2001). Both litter and stems provided dominant drag surfaces in vegetated systems, increasing n by a factor of 10 to 20. However, their presence in the water column did not compensate for water depth and velocity during high flow events (Kadlec and Knight, 1996).

Relationship of succession with increased size of conveyance structure is not intentional, but rather a product of ditch maintenance and hydroperiod. Although maintenance (i.e. dredging and mowing) contributed to lower macrophyte diversity in smaller edge-of-field systems, runoff containing herbicides and excess nutrients from adjacent fields may have affected species diversity in these systems. High vegetative diversity was seen in Western European river communities experiencing little pollution, shading, or recent dredging (Haslam, 1987). Higher plant diversity was seen in our larger study systems and taxa included the persistent *Polygonum* sp., *Leersia* sp., and *Potamogeton* sp. throughout the study sites, demonstrating their resistance to changing hydrological and nutrient regimes. Persistent inundation in Class 4 sites may be the dominant factor reducing occurrence of the upland Poaceae spp.

Various configured systems have been suggested as effective treatments for contaminant removal. These structures range from vertical series of wetland compartments (Brix and Schlerup, 1989; Kadlec and Knight, 1996) to sheet flow through grassed buffer strips entering wetlands (De Laney, 1995) to edge-of-field conveyance systems as wetland substitutes (Moore et al., 2000). In this study, we found forested or grassed buffer strips concurrent with vegetated agricultural conveyance systems provided mitigation areas that reduced agricultural non-point source pollution. Highest nutrient values were measured at sites with limited or no buffer strips and as well, sites with a minimum of 5-m buffer strips provided no measurable nitrate values. Improved surface water quality in the Mississippi Alluvial Delta can result from BMPs that include maintaining sheet flow through established buffer strips and maintenance of agricultural ditches with stable vegetative communities. Buffer strips with a minimum width of 5 to 8 m could include both grassed and forested systems. Water storage and evapotranspiration by forested catchments have been shown to reduce surface flow into receiving systems (Mosley, 1979; Fetter, 2001). Forested buffer zones require years to establish, whereas grassed buffer strips are more easily established and provide functional and transitional ecotones between agricultural fields and conveyance structures.

Establishing stable plant communities within these mitigation areas could enhance nutrient uptake by buffer zones and increase hydraulic retention time with reduced velocity. Although this study did not measure pesticide levels in agricultural ditches, there is ample evidence of increased mitigation of sediments from the water column via adsorption by macrophytes (e.g. Jones and Estes, 1984; Hand et al., 2001; Merlin et al., 2002). De Laney (1995) illustrated that grassed buffer strips can lessen impact from agricultural runoff by alleviation of up to 80% of nutrients and 90–100% of suspended solids entering wetlands. Brix and Schlerup (1989) have also demonstrated 20–50% reduction of nutrients by wetland macrophytes. Optimization of vegetative characteristics of in-place agricultural conveyance structures with subsequent management for treatment of runoff-related contaminants would be an attainable BMP for farm managers. Use of in-place conveyance structures concurrent with vegetated buffer strips could avert potential risk to aquatic systems caused by agricultural non-point contamination, and also preserve valuable agricultural land that might otherwise be dedicated to wetland treatment.

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